APPENDIX I. USGCRP MEMBER AGENCIES

This section summarizes the principal focus areas related to global change research for each USGCRP member agency.

Department of Agriculture

Global change research at the U.S. Department of Agriculture (USDA) is conducted across multiple mission areas and includes contributions from the Agricultural Research Service (ARS), the National Institute of Food and Agriculture (NIFA), the Forest Service (USDA-FS), Natural Resources Conservation Service (NRCS), National Agricultural Statistics Service (NASS), and Economic Research Service (ERS). These USDA entities ensure sustained food security for the Nation and the world. They maintain and enhance the health of U.S. forests and natural resources while identifying risks ranging from temperature and precipitation extremes to the changing infestation ranges and intensities of pests, invasive species, and diseases that result from shifting climatic conditions.

USDA assesses climate change effects on the natural and economic systems associated with productive lands. USDA develops cultivars, cropping systems, and management practices to improve drought tolerance and build resilience to climate variability. USDA promotes integration of USGCRP research findings into farm and natural resource management and helps build resiliency through the development of information products and decision support tools. USDA maintains critical long-term data observation networks including the Long-Term Agro-ecosystem Research (LTAR) Network, the Snowpack Telemetry (SNOTEL) network, the Experimental Forests and Ranges, the Soil Climate Analysis Network (SCAN), the National Resources Inventory (NRI), and the Forest Inventory and Assessment (FIA). USDA's ten Regional Climate Hubs deliver timely and authoritative tools and information to natural resource management professionals, ensuring that the latest science is available to support decision-making. To that end, USDA engages in many communication, outreach, education, and extension efforts across multiple forums to ensure that decision makers, natural resource managers, and stakeholders have access to the most up-to-date scientific information for management decisions.

Department of Commerce

The National Oceanic and Atmospheric Administration (NOAA) and the National Institute of Standards and Technology (NIST) comprise the Department of Commerce's (DOC's) participation in USGCRP.

NOAA's mission is to understand and predict changes in climate, weather, oceans and coasts, to share that knowledge and information with others, and to conserve and manage coastal and marine ecosystems and resources. From supercomputers and state-of-the-art models to observations and outlooks, NOAA provides data, tools, and information to help people understand and prepare for climate variability and change. NOAA's current priorities are (1) to reduce the impact of extreme weather and water events (Weather Act of 2017) and (2) to increase the sustainable economic contributions of our fishery and ocean resources (Blue Economy). NOAA aims to advance its goals and priorities through the following research and development vision areas:

- Reduced societal impacts from severe weather and other environmental phenomena;
- Sustainable use of coastal and ocean resources;
- A robust and effective research, development, and transition enterprise.

NIST works with other federal agencies to develop or extend internationally accepted traceable measurement standards, methodologies, and technologies that enhance measurement capabilities for greenhouse gas emission inventories and measurements critical to advancing climate science research. NIST provides measurements and standards that support accurate, comparable, and reliable climate observations and provides calibrations and special tests to improve the accuracy of a wide range of instruments and techniques used in climate research and monitoring.

Department of Defense

The effects of certain global changes such as climate change are considered national security issues with potential impacts to Department of Defense (DoD) missions, operational plans, and installations. The 2018 National Defense Strategy prioritizes long-term strategic competition with great power competitors by focusing the Department's efforts and resources to: 1) build a more lethal force, 2) strengthen alliances and attract new partners, and 3) reform the Department's processes. To achieve these goals, DoD must be able to adapt current and future operations to address the impacts of a variety of threats and conditions, including those from weather, climate, and other natural events. To that end, DoD factors in the effects of global change into its mission planning and execution to build resilience.

DoD manages and executes research activities across the Services that while addressing specific national security requirements may also be leveraged to address the strategic goals of the USGCRP. The Navy, through the Office of Naval Research, sponsors basic and applied research in potentially relevant broad thrust areas of marine meteorology, physical oceanography, and arctic and global prediction. The Army, primarily through the Army Research Office (ARO) and the US Army Corps of Engineers (USACE) Engineer Research and Development Center (ERDC) sponsor and execute basic and applied research in

relevant areas such as biogeochemical sciences, terrestrial science and phenomenology, and polar science and engineering. The Strategic Environmental Research and Development Program (SERDP), DoD's Joint environmental science and technology program, is planned and executed in partnership with DOE and EPA. SERDP invests in research aimed at enhancing DoD's resilience to a number of environmental threats and includes efforts to develop climate change assessment tools.

Department of Energy

The Department of Energy's (DOE) Office of Science supports fundamental research to address key uncertainties in regional to global-scale Earth system change arising from the interactions and interdependencies of the atmospheric, terrestrial, cryospheric, oceanic, and human-energy components of the Earth system. DOE's research strives to understand and anticipate how environmental and compounding stressors can influence the pattern and magnitude of weather and other extremes, and how these in turn influence the robustness and resilience of U.S. energy infrastructures. Supporting its major role in Earth system prediction, DOE supports long-term field experiments to advance process and systems level understanding; scale-aware parameterizations that can be incorporated into multi-scale models; and advanced software tailored to models that can be ported to DOE's fastest supercomputers. DOE also invests novel machine learning and uncertainty quantification methodologies that allow model products to be more useful to DOE stakeholders. To assist the scientific community in carrying out research, DOE commits significant resources to archiving and management of extensive observed and model-generated data sets for easy retrieval and processing.

There are three areas of DOE research that contribute to the Department's efforts to advance the science of Earth system change: (a) Atmospheric System Research (science of aerosols, clouds, and radiative transfer); (b) Terrestrial Ecosystem Science (role of terrestrial ecosystems and coupled biogeochemical cycles); and (c) advanced modeling that combines development, simulation and analysis. DOE maintains its own suite of advanced modeling platforms, including the Energy Exascale Earth System Model (E3SM), which currently uses DOE's advanced high performance pre-exascale computers; DOE also collaborates with NSF to support the widely-used Community Earth System Model. Using the DOE-supported Program for Climate Model Diagnosis and Intercomparison (PCMDI) and the Earth System Grid Federation, DOE analyzes and distributes large Earth System Model output, with data analytics capabilities available to researchers. The Department also supports the Atmospheric Radiation Measurement (ARM) Research Facility, a scientific user facility based on three permanent observatories and three mobile platforms that in turn provides the research community with unmatched measurements permitting the most detailed high-resolution, three-dimensional documentation of evolving cloud, aerosol, and precipitation characteristics in climate-sensitive sites around the world.

DOE also conducts related applied research involving energy technologies, energy analysis, and prototype infrastructures. The research and analyses undertaken by these offices often requires the development and application of companion models to those used in the Office of Science, e.g., models of energy systems and infrastructures; economics; technology impact; and risk assessment. The applied offices also maintain and update data sets to explore such topics as electric grid stability, water availability for energy production, and siting of energy infrastructure.

Department of Health and Human Services

The U.S. Department of Health and Human Services (HHS) supports a broad portfolio of research and decision support initiatives related to environmental health and the health effects of global climate change, primarily through the National Institutes of Health (NIH) and the Centers for Disease Control and Prevention (CDC). Research focuses on the need to better understand the vulnerabilities of individuals and communities to climate-related changes in health risks such as heat-related morbidity and mortality, respiratory effects of air contaminants affected by climate change, changes in transmission of infectious diseases, and impacts in the aftermath of severe weather events, among many others. Research efforts also seek to assess the effectiveness of various public health adaptation strategies to reduce climate vulnerability, as well as the potential health effects of interventions to reduce greenhouse gas emissions.

Specifically, HHS supports USGCRP by conducting fundamental and applied research on linkages between climate variability and change and health, translating scientific advances into decision support tools for public health professionals, conducting ongoing monitoring and surveillance of climate-related health outcomes, and engaging the public health community in two-way communication about climate change.

Department of the Interior

The U.S. Geological Survey (USGS) conducts global change research for the Department of the Interior (DOI) and constitutes DOI's formal participation in USGCRP.

USGS scientists work with other agencies to provide policy makers and resource managers with scientifically valid information and an understanding of global change and its impacts with the ultimate goal of helping the Nation understand, adapt to, and mitigate global change.

Specifically, the USGS supports research to understand the physical, chemical, and biological components of the Earth system, the causes and consequences of climate and land use change, and the vulnerability and resilience of the Earth system

to such changes. The USGS Land Change Science and National Land Imaging programs (such as the Landsat satellite mission and the National Land Cover Database) provide data that is used to assess changes in land use, land cover, ecosystems, and water resources resulting from the interactions between human activities and natural systems. The science products and datasets from these programs are essential for DOI's biological carbon sequestration project (LandCarbon), which is conducting quantitative studies of carbon storage and GHG flux in the Nation's ecosystems.

USGS also leads the regional DOI Climate Adaptation Science Centers, which deliver science to help fish, wildlife, water, land, and people adapt to a changing climate.

Department of State

The Department of State (DOS) contributes to the Intergovernmental Panel on Climate Change (IPCC), which assesses scientific, technical, and socioeconomic information relevant to the understanding of climate change, its potential impacts, and options for adaptation and mitigation. DOS, with the assistance of USGCRP, coordinates U.S. reviews of IPCC reports to ensure that the reports are a comprehensive, objective, and balanced assessment of the subject matter; nominates U.S. scientists to serve as authors; and represents the United States at IPCC meetings. DOS also works with other agencies in promoting international cooperation in a range of bilateral and multilateral science initiatives and partnerships.

Department of Transportation

The Department of Transportation (DOT) coordinates with USGCRP and its participating agencies to inform transportation system mitigation and resilience solutions. DOT initiatives to improve the resilience of the U.S. transportation sector include:

- The Federal Highway Administration (FHWA) is working with states and metropolitan areas to increase the health and longevity of the Nation's highways through an ongoing program of assessing vulnerabilities; considering resilience in the transportation planning process; incorporating resilience in asset management plans; addressing resilience in project development and design; and optimizing operations and maintenance practices.

- The Maritime Administration (MARAD) Ports Team is scoping a framework for a proposed asset management tool called the Waterfront Asset Management Tool (WFAM) for domestic port planning. This proposed asset management tool would assist public and private ports with tools to establish risk-based asset management plans to prioritize maintenance dollars and provide justification for spending scarce funding for maintenance and/or resiliency priorities.

- The Office of the Assistant Secretary for Research and Technology (OST-R) is working in partnership with the FHWA and the OST Office of Intelligence, Security, and Emergency Response to ensure that the costs and benefits of resilience are incorporated into the transportation infrastructure planning process. The goal is to develop nationally-replicable modelling tools capable of estimating the regional-scale impacts of natural and man-made disasters on the transportation system. These tools will enhance pre-event planning and disaster recovery capabilities.

Environmental Protection Agency

The core purpose of the Environmental Protection Agency's (EPA's) global change research program is to develop scientific information that supports policy makers, stakeholders, and society at large as they respond to climate change and associated impacts on human health, ecosystems, and socioeconomic systems. EPA's research is driven by the Agency's mission and statutory requirements, and includes (1) improving scientific understanding of global change effects on air quality, water quality, ecosystems, and human health in the context of other stressors; (2) assessing and defining adaptation options to effectively prepare for and respond to global change risks, increase resilience of human and natural systems, and promote their sustainability; and (3) developing an understanding of the potential environmental and human health impacts of greenhouse gas emission reduction technologies and approaches to inform sustainable mitigation solutions. EPA Program Offices and Regions leverage this research to support mitigation and adaptation decisions, as well as inform communication with external stakeholders and the public.

EPA relies on USGCRP to develop high-quality scientific models, data, and assessments to advance understanding about physical, chemical, and biological changes to the global environment and their relation to drivers of global climate change. Satellite and other observational efforts conducted by USGCRP agencies are crucial to supporting EPA's efforts to understand how land use change, population change, climate change, and other global changes are affecting ecosystems and the services they provide. EPA's global change research applies and extends these results using regional and local air quality, hydrology, and sea level rise models to better understand the impacts of climate change to specific human health and ecosystem endpoints. These connections enable local, regional, and national decision-makers to develop and implement strategies to protect human health and the environment. In turn, EPA's research provides USGCRP agencies with information and understanding about the connections between global change and impacts at local, regional, and national scales, as well as how mitigation and adaptation actions may influence global changes.

EPA's research informs approaches to prepare for, adapt to, and minimize the impacts of climate change, including extreme weather events, wildfire, and rising sea levels, and their impacts on human health and well-being and social and economic

systems. Other EPA activities include applying long-term datasets, analytical tools, and models to examine and communicate observed climate change indicators and project impacts and economic damages associated with global mitigation scenarios. EPA's technical assistance and analytical expertise supports state and local decision makers seeking to identify, prioritize, and implement adaptation work within their environmental programs.

National Aeronautics and Space Administration

NASA's global change activities have four integrated foci: satellite observations, research and analysis, applications, and technology development. Satellites provide critical global atmosphere, ocean, land, sea ice, and ecosystem measurements. NASA's 22 on-orbit missions (as of July 2019) measure numerous variables required to enhance understanding of Earth interactions. In 2018, NASA launched the Gravity Recovery and Climate Experiment Follow On (GRACE-FO) dual-satellite mission with its German partner GFZ (German Research Centre for Geosciences) to restart the record from the 2002–2017 GRACE satellite mission. GRACE-FO is now continuing the work of tracking Earth's water movement to monitor changes in underground water storage, the amount of water in large lakes and rivers, soil moisture, ice sheets and glaciers, and sea level caused by the addition of water to the ocean. The ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) instrument, launched to the International Space Station (ISS) in 2018, is now measuring the surface temperature of plants and using that information to better understand how much water plants need and how they respond to stress. The Ice, Cloud, and land Elevation Satellite (ICESat-2) and the Global Ecosystem Dynamics Investigation (GEDI) also launched in 2018. ICESat-2 is measuring the elevation of ice sheets, glaciers, and sea ice in unprecedented detail, continuing the record of ICESat and making coordinated measurements with Operation Ice Bridge under-flights. GEDI is measuring the structure of Earth's tropical and temperate forests in high resolution and three dimensions from the ISS. In 2019, the Orbiting Carbon Observatory 3 (OCO-3) launched to the ISS and is now adding to the record of global carbon dioxide (CO2) measurements taken by OCO-2. OCO-3 focuses on understanding the regional sources and sinks of CO2 from the unique vantage point of the ISS. Several small (U-Class) satellites (also known as CubeSats) deployed from the International Space Station in 2018 as part of NASA's Earth Science Technology InSpace Validation of Earth Science Technologies (InVEST) program and began taking their first measurements and sending data to the ground. Four new projects were also selected as part of the InVEST program: SNOO-PI: SigNals-Of-Opportunity P-band Investigation; Hyperspectral Thermal Imager (HyTI); Compact Total Irradiance Monitor Flight Demonstration; and, High-Resolution Trace-Gas Hyperspectral Imagers, with Agile On-board Processing.

In August 2019, NASA announced that it selected a space-based instrument under its Earth Venture Instrument (EVI) portfolio that will make observations to improve our understanding of the biology, chemistry, and ecology of coastal waters to help protect ecosystem sustainability, improve resource management, and enhance economic activity. The selected Geosynchronous Littoral Imaging and Monitoring Radiometer (GLIMR) instrument will provide unique observations the Gulf of Mexico, portions of the southeastern United States coastline, and the Amazon River plume—where the waters of the Amazon River enter the Atlantic Ocean. GLIMR will be integrated on a NASA-selected platform and launched in the 2026-2027 timeframe into a geosynchronous orbit where it will be able to monitor a wide area, centered on the Gulf of Mexico, up to seven times a day. This hyperspectral ocean color radiometer will measure the reflectance of sunlight from optically complex coastal waters in 141 narrow wavebands.

NASA's program advances observing technology and leads to new and enhanced space-based observation and information systems. The Earth science research program explores interactions among the major components of the Earth system—continents, oceans, atmosphere, ice, and life—to distinguish natural from human-induced causes of change and to understand and predict the consequences of change. NASA makes significant investments to assure the quality and integration of data through calibration and validation efforts that include satellite, surface, and airborne measurements, as well as data intercomparisons. NASA also carries out observationally driven modeling projects that include data assimilation, reanalysis, process representation, initialization, and verification.

In 2018, the Long Island Sound Tropospheric Ozone Study (LISTOS) multi-agency (e.g., NOAA, EPA, and multiple state-level agencies) collaborative study focused on Long Island Sound and the surrounding coastlines that continue to suffer from poor air quality exacerbated by land/water circulations. The primary measurement operations took place between June-September 2018. Campaigns initiated in 2019 include the Cloud, Aerosol and Monsoon Processes Philippines Experiment (CAMP2Ex) (conducted with the Naval Research Laboratory and Manila Observatory), which will investigate cloud formation in the western part of the Philippines, one of the world's most unpredictable geographic regions for weather and climate model, and the Fire Influence on Regional to Global Environments Experiment - Air Quality (FIREX-AQ) (conducted with NOAA). Fire emissions in the United States derive approximately half from Northwestern wildfires and half from prescribed fires that burn mostly in the Southeast U.S.; FIREX-AQ will investigate both wild and prescribed fires.

Five new NASA Earth science campaigns part of NASA's Earth Venture-class program, selected in 2018, will take to the field starting in 2020.

Applications projects extend the societal benefits of NASA's research, technology, and spaceflight programs to the broader U.S. public through the development and transition of user-defined tools for decision support, and are focused on such areas as water resources, health/air quality, and ecological forecasting. The Earth science technology program funds, develops and demonstrates a broad range of cutting-edge technologies—from new instruments and components to advanced modeling and information systems—to enable new capabilities, and reduces the cost, risk, and/or development times for Earth science instruments.

National Science Foundation

The National Science Foundation (NSF) addresses global change issues through investments that advance frontiers of knowledge, provide state-of-the-art instrumentation and facilities, develop new analytical methods, and enable cross-disciplinary collaborations while also cultivating a diverse, highly trained workforce and developing educational resources. In particular, NSF global change programs support the research and related activities to advance fundamental understanding of physical, chemical, biological, and human systems and the interactions among them. The programs encourage interdisciplinary approaches to studying Earth system processes and the consequences of change, including how humans respond to changing environments and the impacts on ecosystems and the essential services they provide. NSF programs promote the development and enhancement of models to improve understanding of integrated Earth system processes and to advance predictive capability. NSF also supports fundamental research on the processes used by organizations and decision makers to identify and evaluate policies for mitigation, adaptation, and other responses to the challenge of a changing and variable environment. Long-term, continuous, and consistent observational records are essential for testing hypotheses quantitatively and are thus a cornerstone of global change research. NSF supports a variety of research observing networks that complement, and are dependent on, the climate monitoring systems maintained by its sister agencies.

NSF regularly collaborates with other USGCRP agencies to provide support for a range of multi-disciplinary research projects and is actively engaged in a number of international partnerships.

Smithsonian Institution

Within the Smithsonian Institution (SI), global change research is primarily conducted at the National Air and Space Museum, the National Museum of Natural History, the National Zoological Park, the Smithsonian Astrophysical Observatory, the Smithsonian Environmental Research Center, and the Smithsonian Tropical Research Institute. Research is organized around themes of atmospheric processes, ecosystem dynamics, observing natural and anthropogenic environmental change on multiple time scales, and defining longer-term climate proxies present in the historical artifacts and records of the museums as well as in the geologic record. Most of these units participate in the Smithsonian's Global Earth Observatories, examining the dynamics of forests (ForestGEO, formerly SIGEO) and coastal marine habitats (MarineGEO) over decadal time frames.

The Smithsonian also brings together researchers from around the Institution to focus on joint programs aimed at estimating volcanic emissions, understanding and sustaining biodiversity, monitoring animal migrations, characterizing working landscapes and seascapes, or studying emerging infectious diseases in wildlife and humans. Smithsonian paleontological research documents and interprets the history of terrestrial and marine ecosystems from 400 million years ago to the present. Other scientists study the impacts of historical environmental change on the ecology and evolution of organisms, including humans. Archaeobiologists examine the impact of early humans resulting from their domestication of plants and animals, creating the initial human impacts on planetary ecosystems.

These activities are joined by related efforts in the areas of history and art, such as the Center for Folklife and Cultural History, the National Museum of the American Indian, the Anacostia Community Museum, the National Museum of African American History and Culture, and the Cooper Hewitt Museum of Design to examine human responses to global change, within communities, reflected in art and culture, food, and music. Finally, Smithsonian outreach and education programs expand our scientific and social understanding of processes of change and represents them in exhibits and programs, including at the history and art museums of the Smithsonian. USGCRP funding enables the Smithsonian to leverage private funds for additional research, education, and outreach programs on these topics.

U.S. Agency for International Development

The U.S. Agency for International Development (USAID) carries out climate change and development work in four main areas: energy, sustainable landscapes, climate resilience, and climate risk management. USAID supports global research and analysis and partners bilaterally with dozens of countries to build capacity, address governance, and create the legal and regulatory environment needed to address climate change and development. This work is integral to helping countries pursue economic growth, stability, and self-reliance.

Energy: USAID helps partner countries build strong energy sectors that can attract private investment and power global economic and social development. USAID's efforts support least-cost modern energy solutions. In many countries, renewable energy is now the least-cost solution that maximizes development impact.

Sustainable landscapes: USAID supports research on estimating and accounting for land-based carbon stocks and greenhouse gas fluxes, and on governance and finance in the land sector, all with a focus on developing countries. USAID also supports partner countries in meeting their commitments to reduce land-based greenhouse gas emissions, often through activities that promote conservation, restoration, and sustainable use of forests, agriculture, and other lands. By improving landscape management, USAID helps to curb destruction and degradation, improve livelihoods, and increase resilience.

Climate resilience: USAID works with partner countries to build climate resilience and disaster preparedness to weather and climate-related shocks and stresses such as droughts, floods, and shifting rainfall patterns. Improved weather and climate information, informed land use planning, and smart infrastructure design are some ways communities can prepare for these risks and avoid setbacks. Thinking ahead and proactively managing risks help sustain livelihoods and maintain critical services, reducing the need for costly disaster response.

Climate risk management (CRM): CRM is an internal USAID practice to assess, address and manage climate risk in new strategies, projects, and activities across USAID's development portfolio, safeguarding U.S. investments through informed decision-making.

With over seventy overseas missions, USAID enables decision makers to apply high-quality climate information to their decision making and enables countries to accelerate their transition to climate resilient, sustainable economic development. USAID achieves these objectives through direct programming and integration of climate change adaptation and mitigation activities into the broader development portfolio.

USAID leverages scientific and technical resources from across the U.S. Government, private sector partners, and nongovernmental organizations and science institutes to develop and implement low-emissions development strategies, creating policy frameworks for market-based approaches to emission reduction and energy sector reform, promoting sustainable management of agricultural lands and forests, protecting biodiversity, and mainstreaming adaptation into development activities in countries most at risk to advance resilient and sustainable development.